

12

USAARL REPORT NO. 84-6

AD-A140 634

**IN-FLIGHT EVALUATION OF TWO MOLECULAR SIEVE  
OXYGEN CONCENTRATION SYSTEMS IN U.S. ARMY  
AIRCRAFT (JUH-1H AND JU-216)**

By  
**William A. Chaffin, Jr.**  
**Bruce F. Hiott**  
**Francis S. Knox III**

**BIOMEDICAL APPLICATIONS RESEARCH DIVISION**

**March 1984**

DTIC  
ELECTRONIC  
MAY 1 1984  
A

**U.S. ARMY AEROMEDICAL RESEARCH LABORATORY  
FORT RUCKER, ALABAMA 36362**

DTIC FILE COPY

**USAARL**

84 05 01 004

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER USAARL Report No. 84-6		2. GOVT ACCESSION NO. A1-A140 634	
3. TITLE (and Subtitle) In-Flight Evaluation of Two Molecular Sieve Oxygen Concentration Systems in U.S. Army Aircraft (JUH-1H and JU-21G)		3. RECIPIENT'S CATALOG NUMBER	
4. AUTHOR(s) William Chaffin, Jr. Bruce F. Hiott Francis S. Knox III		5. TYPE OF REPORT & PERIOD COVERED Final Report	
5. PERFORMING ORGANIZATION NAME AND ADDRESS SGRD-UAB-CB US Army Aeromedical Research Laboratory Fort Rucker, Alabama 36362		6. PERFORMING ORG. REPORT NUMBER	
6. CONTROLLING OFFICE NAME AND ADDRESS US Army Medical Research and Development Command Fort Detrick Frederick, Maryland 21701		7. CONTRACT OR GRANT NUMBER(s)	
7. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		8. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62777A, 3E162777A878, AF 134	
8. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		9. REPORT DATE March 1984	
9. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		10. NUMBER OF PAGES 38	
10. SUPPLEMENTARY NOTES		11. SECURITY CLASS. (of this report) Unclassified	
11. KEY WORDS (Continue on reverse side if necessary and identify by block number) Molecular sieve      Oxygen Concentrators Zeolite              Pressure Differential Pressure Swing		12. DECLASSIFICATION/DOWNGRADING SCHEDULE	
12. ABSTRACT (Continue on reverse side if necessary and identify by block number) See back of form.		13. Accession For NTIS GRA&I <input checked="" type="checkbox"/> DTIC TAB <input type="checkbox"/> Unannounced <input type="checkbox"/> Justification	
		14. Distribution/ Availability Codes Avail and/or Dist      Special A-1	

DD FORM 1473

1 JAN 73

EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT:

The logistical problems associated with using high pressure gaseous oxygen systems have encouraged the development of molecular sieve oxygen concentration systems for use on board aircraft. This report summarizes the in-flight static performance characteristics of two such oxygen concentrators installed in a JU-21G fixed-wing, twin-engine turbopropeller aircraft and a JUH-1H turbine-powered helicopter. Flight profiles consisting of five separate flights at altitudes of 1,524, 3,048, 4,572, 6,096, and 7,620 meters (5,000, 10,000, 15,000, 20,000, and 25,000 feet) were flown in the JU-21G and five separate flights at altitudes of 1,524, 3,048 and 4,572 meters were flown in the JUH-1H. Oxygen concentration at flows of 15, 25, 35, and 70 liters per minute were recorded at each altitude. These flows were chosen to represent normal breathing requirements for one- and two-man crews. In all cases, the concentrators met or exceeded the requirements of MIL-R-83178. The use of engine bleed air to drive the oxygen concentrators produced no noticeable effect on aircraft performance.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

## NOTICE

### Qualified Requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

### Change of Address

Organizations receiving reports from the US Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

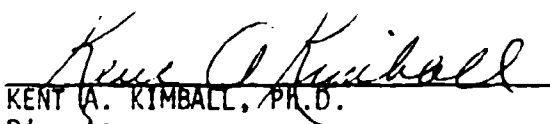
### Disposition

Destroy this report when it is no longer needed. Do not return it to the originator.

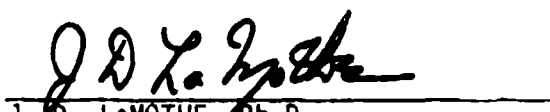
### Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Reviewed:

  
KENT A. KIMBALL, PH.D.  
Director  
Biomedical Applications Research  
Division

Released for Publication:

  
J. D. LaMOTHE, Ph.D.  
LTC, MS  
Chairman, Scientific Review  
Committee

  
DUDLEY R. PRICE  
Colonel, MC, SFS  
Commanding

## ACKNOWLEDGEMENT

The authors take this opportunity to acknowledge with thanks the many valuable contributions by LTC Philip Taylor and SFC Richard Weber during the data collection, data analysis, and writing/editorial phases of this project.

## TABLE OF CONTENTS

	PAGE NO.
List of Illustrations. . . . .	2
List of Tables . . . . .	3
Introduction . . . . .	4
Apparatus. . . . .	6
Procedure. . . . .	11
Results. . . . .	11
Discussion . . . . .	26
Conclusions. . . . .	27
References Cited . . . . .	30
Appendix A - Equipment and Manufacturer List . . . . .	31

# LIST OF ILLUSTRATIONS

FIGURE	PAGE NO.
1. Molecular Sieve Block Diagram. . . . .	5
2. JU-21G Research Aircraft . . . . .	7
3. JUH-1H Research Aircraft . . . . .	8
4. Oxygen Concentrators . . . . .	9
5. Test Stand . . . . .	10
6. Oxygen Concentration vs. Altitude in JU-21G (Bendix Unit, Minimum Power) . . . . .	12
7. Oxygen Concentration vs. Altitude in JU-21G (Bendix Unit, Maximum Power) . . . . .	13
8. Oxygen Concentration vs. Altitude in JU-21G (Garrett Unit, Minimum Power). . . . .	14
9. Oxygen Concentration vs. Altitude in JU-21G (Garrett Unit, Maximum Power). . . . .	15
10. Oxygen Concentration vs. Altitude in JUH-1H (Bendix Unit). . . . .	16
11. Oxygen Concentration vs. Altitude in JUH-1H (Garrett Unit) . . . . .	17
12. Oxygen Concentration vs. Altitude in JU-21G (Garrett Unit, Minimum Power). Supplemental Data. . . .	28
13. Oxygen Concentration vs. Altitude in JU-21G (Garrett Unit, Maximum Power). Supplemental Data. . . .	29

# LIST OF TABLES

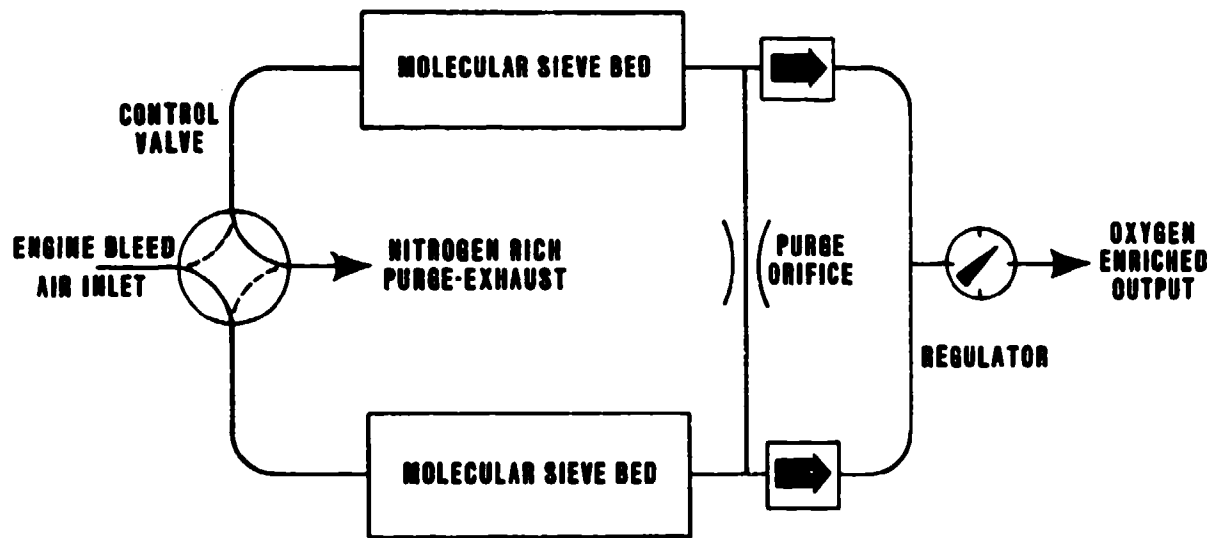
TABLE	PAGE NO.
1. Oxygen Concentration and System Condition Under Static Flow (Bendix/JU-21G) . . . . .	18
2. Oxygen Concentration and System Condition Under Static Flow (Garrett/JU-21G) . . . . .	20
3. Oxygen Concentration and System Condition Under Static Flow (Bendix/JUH-1H) . . . . .	22
4. Oxygen Concentration and System Condition Under Static Flow (Garrett/JUH-1H) . . . . .	23
5. Oxygen Concentration and System Condition Under Static Flow (Garrett/JU-21G). Supplemental Data . . . .	24

## INTRODUCTION

In 1947, with the formation of the US Air Force as a separate branch of service, US Army aviation relinquished most of its high-altitude capabilities, requirements, and aircraft, resulting in a role of reduced importance for oxygen delivery systems in the Army aviation environment. Today, however, there are increased mission requirements, both training and operational, which dictate routine flights in certain aircraft to altitudes as high as 7,620 meters (25,000 feet) in an unpressurized cabin. As a result, oxygen systems are again a critical part of US Army aircraft life support systems. Currently, US Army aviation oxygen needs are satisfied only partially by continuous flow and diluter demand gaseous oxygen systems due to space, weight, and logistical limits. Additionally, the effectiveness of these systems is compromised by several factors. The amount of oxygen available during a given flight is limited by the number of high-pressure cylinders carried on board the aircraft. Carrying extra cylinders results in a weight and space penalty which reduces operational aircraft capability. Gaseous systems require frequent refilling which prolongs aircraft turnaround time. There also are high risk safety hazards associated with the storage, servicing, and use of high pressure gaseous oxygen systems; and logistical servicing facilities are not normally available at remote locations.

The logistical problems associated with using high pressure gaseous oxygen systems have encouraged the development of molecular sieve oxygen concentration systems for use on board aircraft. The US Army, Navy, and Air Force are studying the applicability of these systems for use on high performance jet aircraft, turbopropeller aircraft, and turbine-powered helicopters (Ernsting et al., 1980; Knox et al., 1981; Miller et al., 1980; and Pettyjohn et al., 1977).

A typical concentrator contains two canisters or "beds" filled with a synthetic zeolite molecular sieve material of five Angstrom pore size. These two beds are pressurized alternately with bleed air diverted from the compressor stage of the turbine engine. During pressurization, oxygen in the bleed air is separated from nitrogen and then vented through the output port. Nitrogen is trapped in the zeolite molecular sieve material. The bed then is depressurized to the atmosphere as a nitrogen exhaust purge which completes the unit's "pressure swing cycle." During this phase of the cycle, some of the concentrated oxygen from the pressurized bed is bled in the reverse direction through the depressurized bed to assist in the nitrogen purge. Thus, when one bed is concentrating oxygen, the other is being purged of nitrogen. A rotary valve directs the flow of bleed air and also controls the flow of oxygen-enriched air and nitrogen purge. The valve is actuated by a 28-volt DC motor that is powered by the aircraft electrical system. A block diagram of this process is shown as Figure 1. This report summarizes the in-flight static performance characteristics of two such oxygen concentrators installed in a



**MOLECULAR SIEVE BLOCK DIAGRAM**

FIGURE 1. Molecular Sieve Block Diagram

JU-21G fixed-wing, twin-engine, turbopropeller aircraft (Figure 2) and a JUH-1H turbine-powered helicopter (Figure 3). Such an effort is a necessary first step for evaluation of candidate systems within the range of physiological requirements.

## METHOD

### APPARATUS

Two oxygen concentrators were tested, one manufactured by the Garrett Corporation\* and the other by the Bendix Corporation\* (Figure 4). Each unit occupies approximately one cubic foot and operates by basically the same method.

In the JU-21G, instrumentation for in-flight testing and data collection was installed in a specially-built test stand (Figure 5). Bleed air from the right engine at 15 to 55 pounds per square inch gauge (psig) was fed into the test stand through a 15.78mm (5/8-inch) internal diameter (ID) oxygen line. A 4.5-liter plenum chamber was installed to facilitate instrumentation and dampen pressure fluctuations caused by the pressure swing of the molecular sieve concentrator. Inlet bleed air pressure was measured by a Validyne differential pressure transducer\* and a Harris sight gauge.\* Temperature was measured with a Cole-Palmer digital thermometer\* before the air was directed from the plenum chamber through the oxygen concentrator. The oxygen-enriched air (product gas) exited the concentrator and passed into a second 4.5-liter plenum chamber where the outlet pressure and temperature again were monitored and recorded using another Validyne differential pressure transducer, Harris sight gauge, and Cole-Palmer digital thermometer. Upon exiting the outlet plenum, the product gas was fed through a 9.5mm (3/8-inch) ID oxygen line to a Technology, Incorporated mass flow meter.\* A shutoff valve, in conjunction with a Fischer-Porter rotameter\*, was used to set various flows. Oxygen concentration was measured using a fast response Beckman OM-14 oxygen analyzer\* equipped with an altitude sensor. A Wallace and Tiernan barometer\* was used to measure ambient barometric pressures. Standard aircraft instrumentation was used for torque, engine temperature, airspeed, and altitude measurements. Calibration of instrumentation was maintained on a flight-by-flight basis at both ground level and at the various sampling altitudes.

The same instrumentation package was used for testing in the JUH-1H with the only difference being a slight modification of the test stand to allow for proper securing of the stand to the helicopter's cargo attachment points.

---

\*Indicates product manufacturer listed in Appendix A.

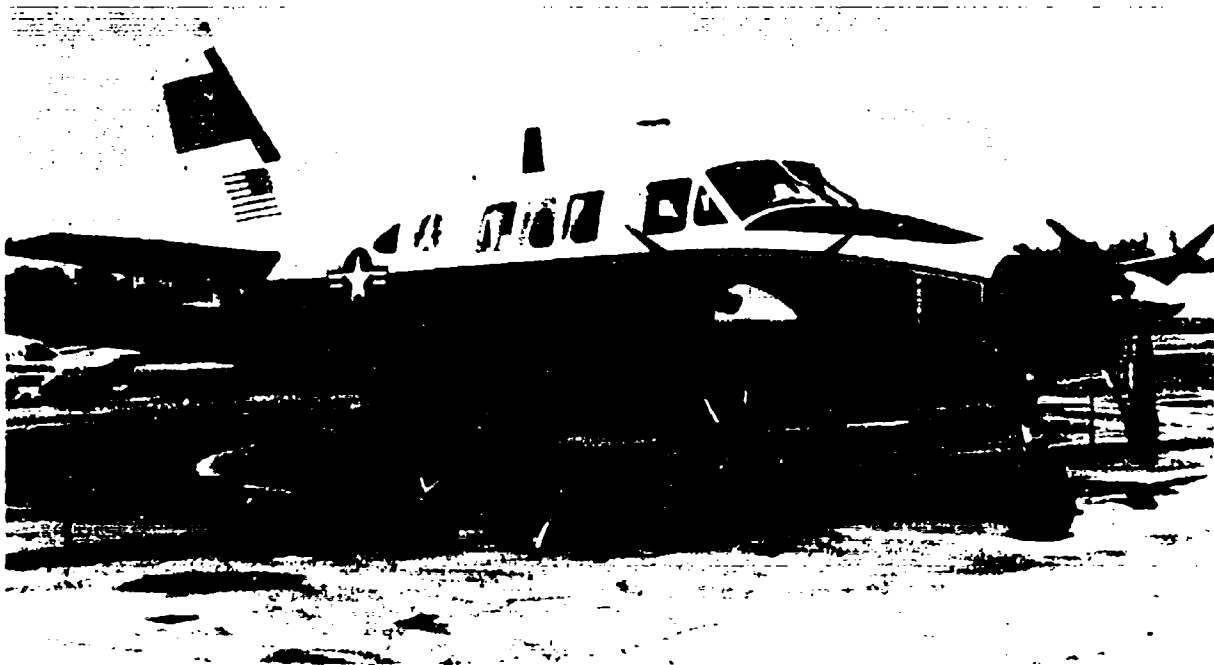


FIGURE 2. JU-21G Research Aircraft.



FIGURE 3. JUH-1H Research Aircraft.

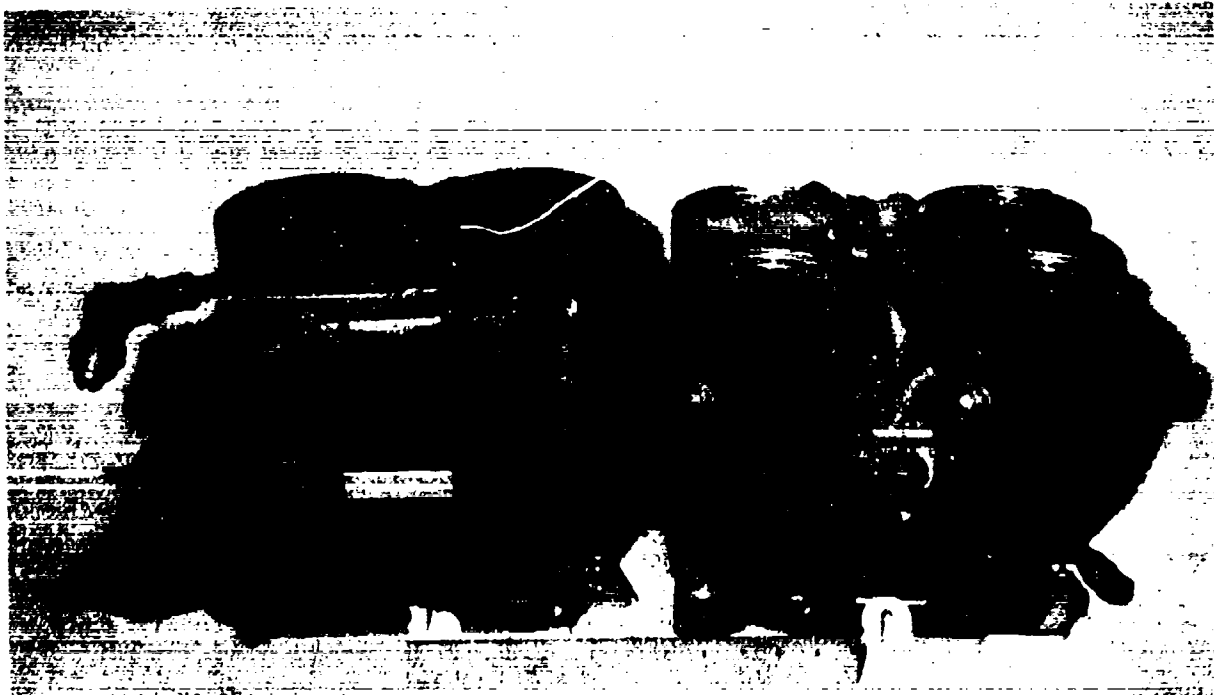


FIGURE 4. Oxygen Concentrators--Bendix Unit (Left), Garrett Unit (Right).

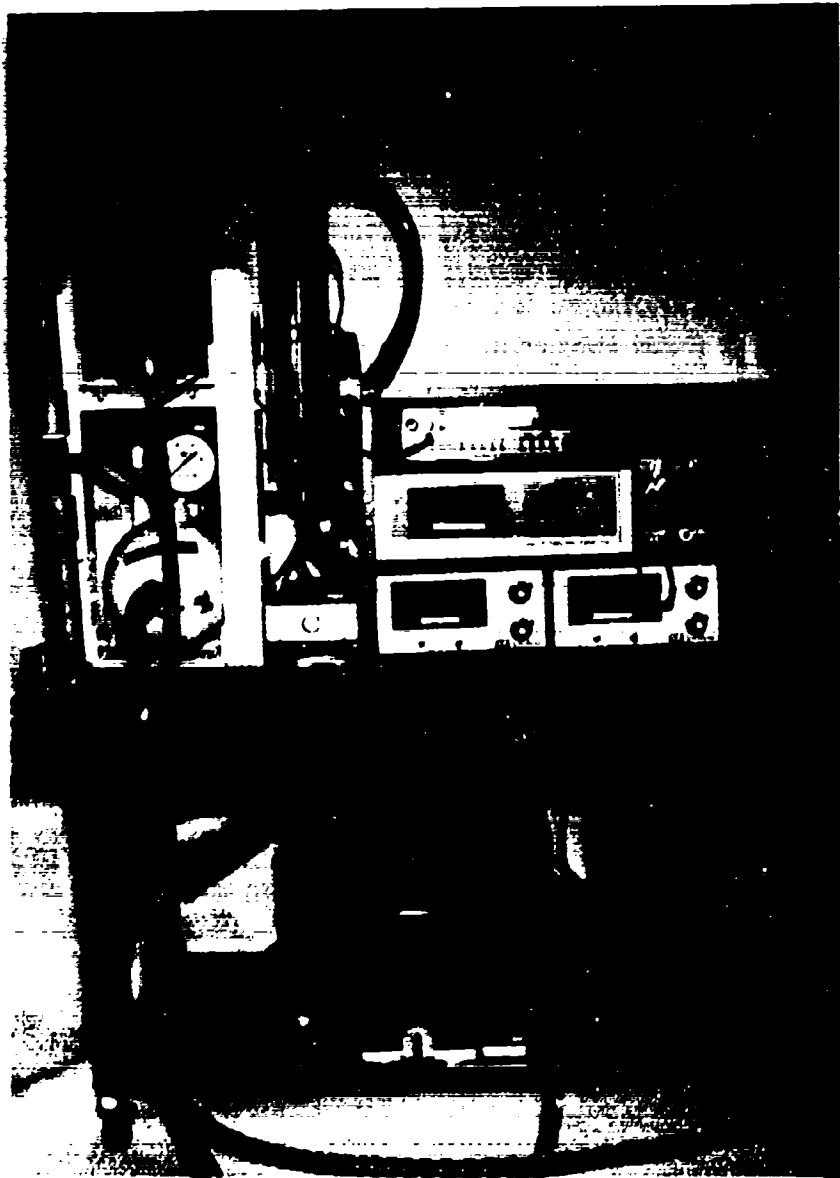


FIGURE 5. Test Stand.

## PROCEDURE

In the JU-21G, five separate flights at altitudes of 1,524, 3,048, 4,572, 6,096, and 7,620 meters (5,000, 10,000, 15,000, 20,000, and 25,000 feet) were conducted with each oxygen concentration unit. Four different flows of 15, 25, 35, and 70 liters per minute were chosen to represent normal breathing requirements for one- and two-man crews. Data were recorded for each flow at all altitudes and at both minimum and maximum engine power settings. Minimum power was defined as the power required to fly at 130 knots indicated airspeed (IAS) while maximum power was defined as 208 knots IAS with Interstage Turbine Temperature (ITT) not to exceed 705°C. At these power settings, the inlet bleed air pressures at the oxygen concentrator were consistently in the range of 28 to 55 psig and oxygen-enriched air outlet pressure ranged from 22 to 28 psig, which is well within the limits of the low pressure oxygen regulators designed for use with molecular sieve oxygen concentration units. In the JUH-1H, five separate flights at altitudes of 1,524, 3,048, and 4,572 meters (5,000, 10,000, and 15,000 feet) were conducted with each oxygen concentration unit. Flow rates were the same as in the JU-21G, and the engine power setting was constant over the entire flight test period.

## RESULTS

Oxygen concentrations and other system considerations for the JU-21G flights are shown for the Bendix unit in Table 1 and for the Garrett unit in Table 2. Oxygen concentration and system data for the JUH-1H flights are shown in Table 3 for the Bendix unit and in Table 4 for the Garrett unit. Generally, with both units, oxygen concentration decreased with increased flow and increased with higher altitude. In the JU-21G, oxygen concentration generally decreased with the higher engine power setting. However, with the Bendix unit, this condition was reversed in some instances. In all cases, as shown in Figures 6 through 11, oxygen concentration met or exceeded the requirements (indicated by the stippled area) of MIL-R-83178.

Data first recorded upon reaching a new altitude (low flows, Figures 6-9) often showed overlap where it was supposed there should be none. A careful review of data collection procedures revealed that it usually took 4 to 6 minutes for the system to stabilize and be repeatable. In order to test the working hypothesis that the initial readings in Figures 6 through 9 were taken prior to system equilibrium, data were recorded during three additional flights in the JU-21G at each altitude, allowing more time between flow changes and altitude changes for the system to stabilize. The data for the Garrett unit is presented in Table 5 and Figures 12 and 13 for these additional flights. Two low-altitude flights were made with the Bendix unit when the aircraft

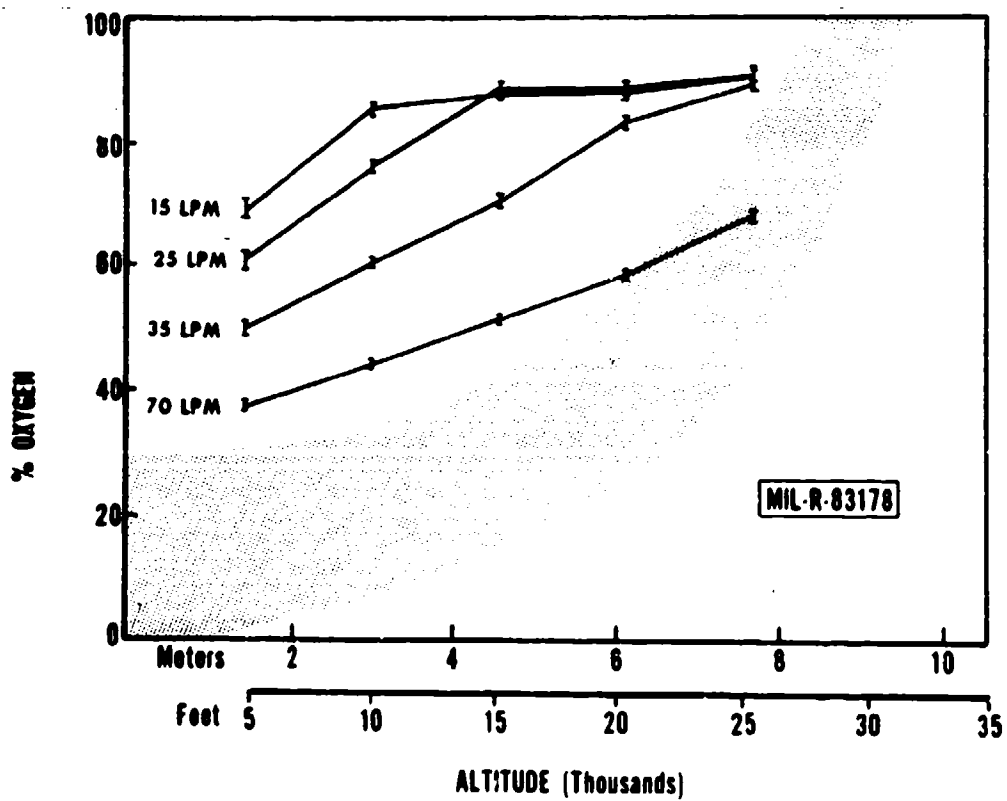


FIGURE 6. Oxygen concentration vs. altitude in JU-21G (Bendix unit, minimum power). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

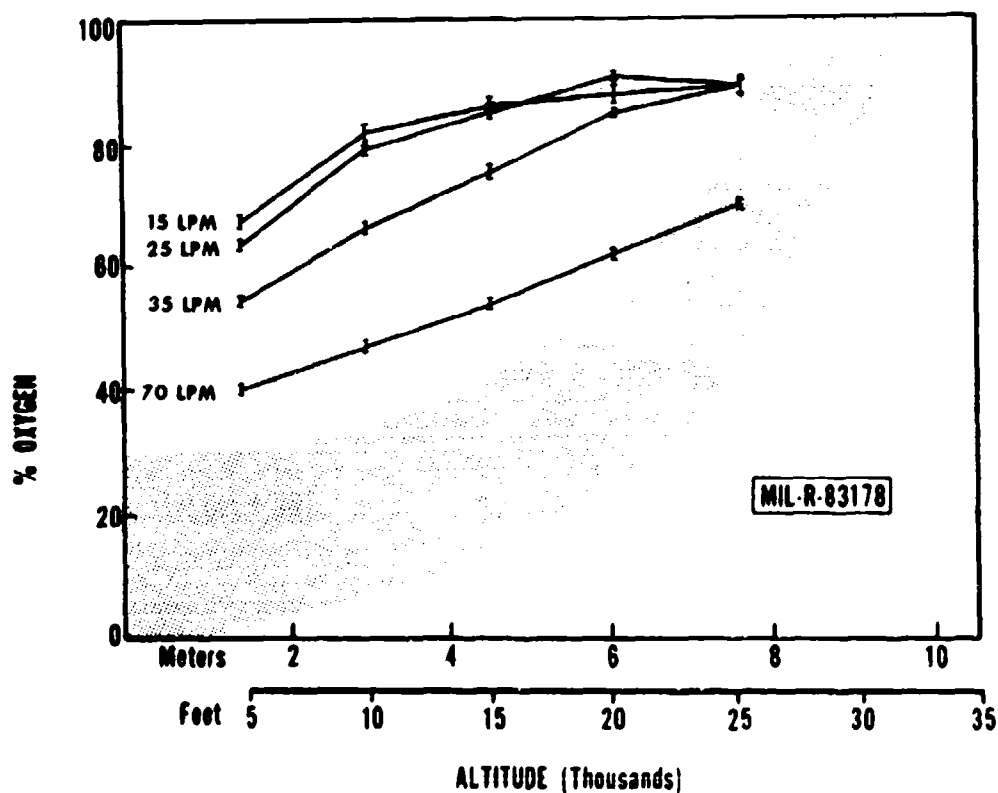


FIGURE 7. Oxygen concentration vs. altitude in JU-21G (Bendix unit, maximum power). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

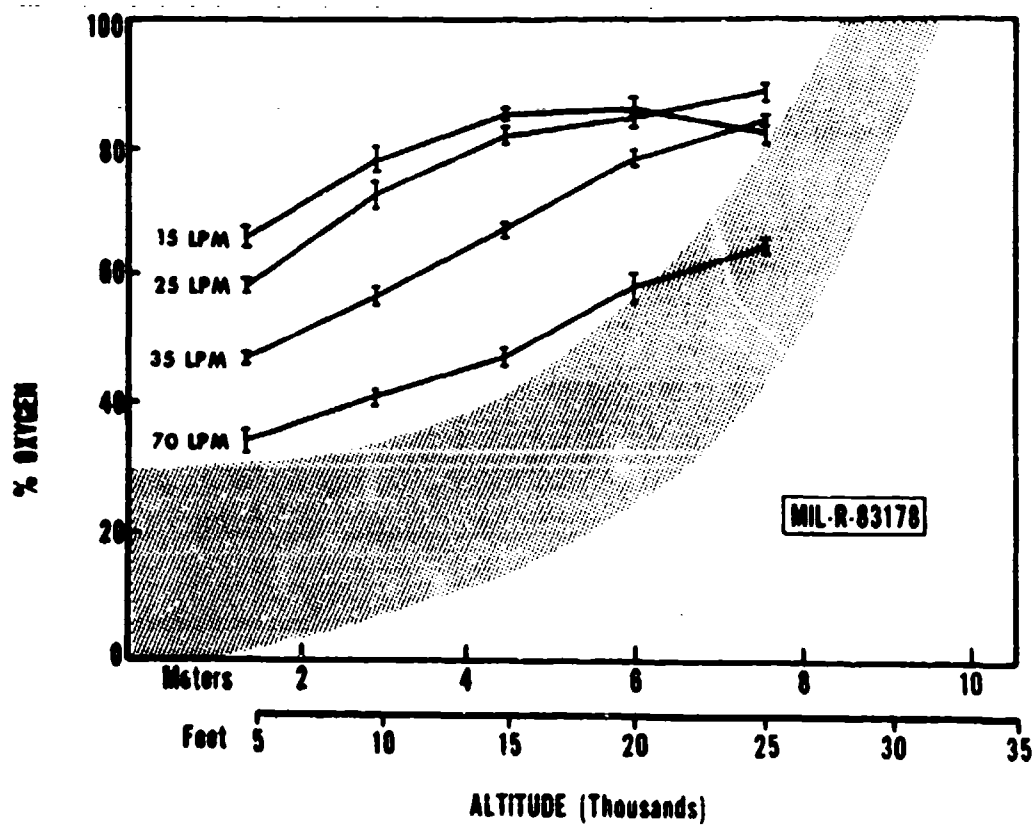


FIGURE 8. Oxygen concentration vs. altitude in JU-21G (Garrett unit, minimum power). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

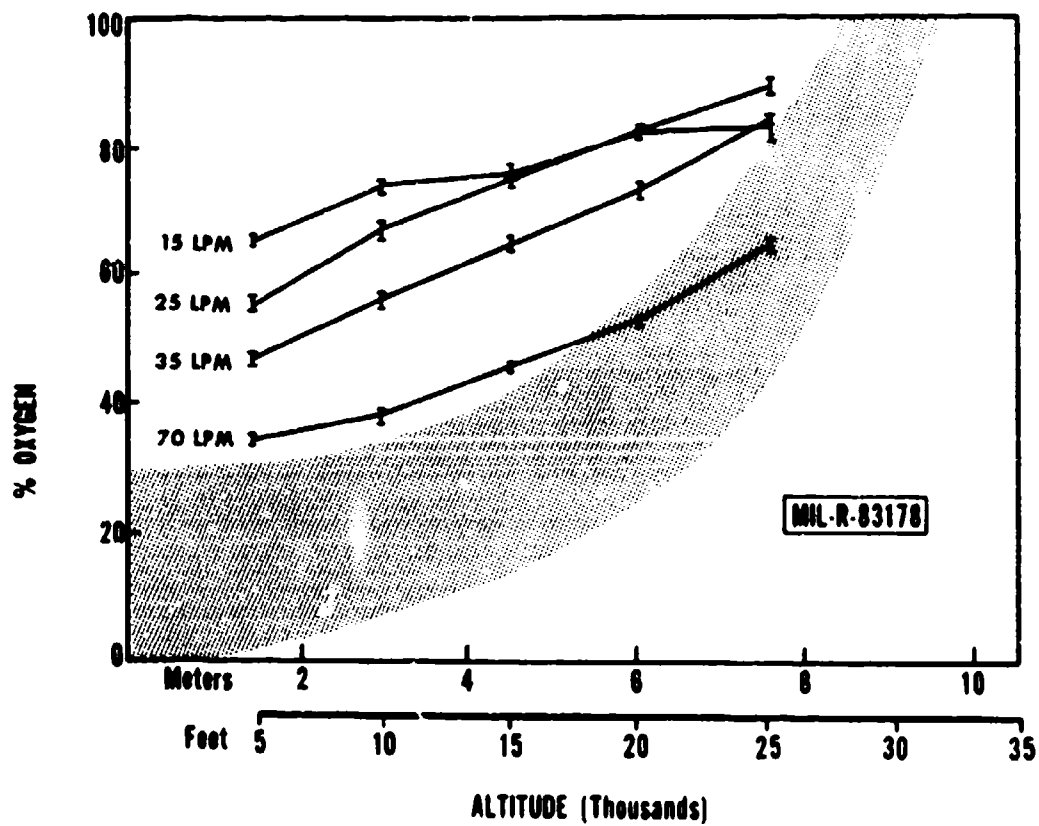


FIGURE 9. Oxygen concentration vs. altitude in JU-21G (Garrett unit, maximum power). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

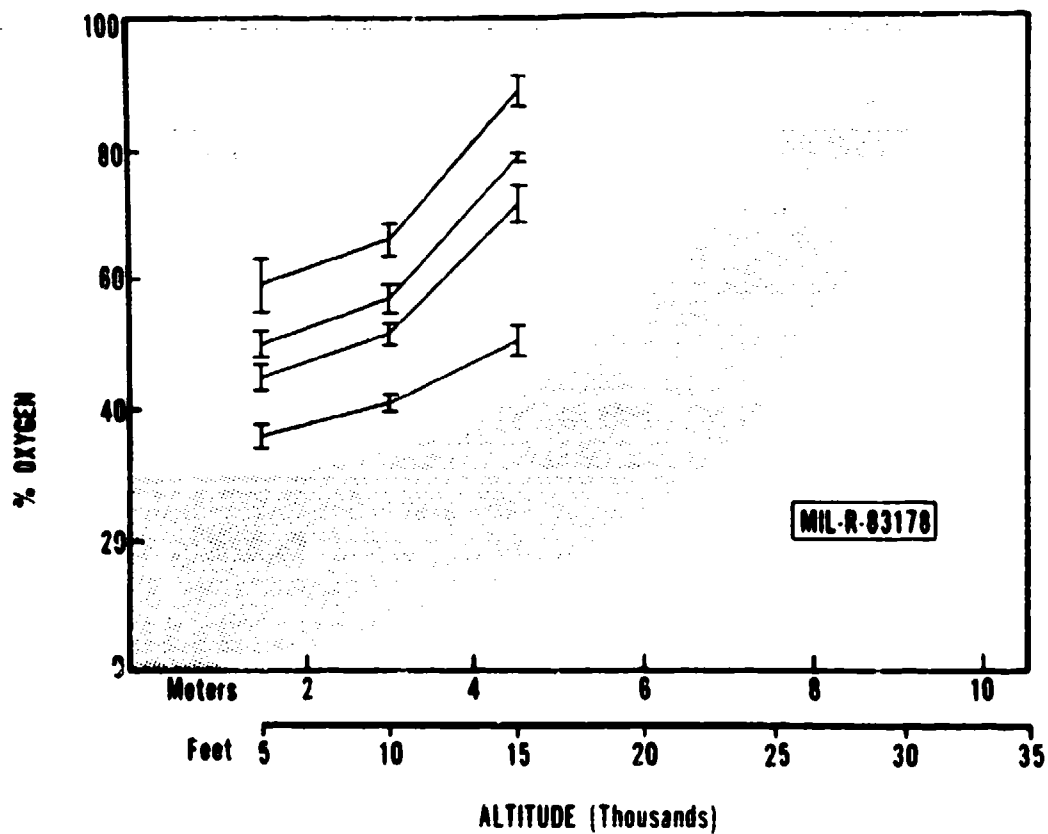


FIGURE 10. Oxygen concentration vs. altitude in JUH-1H (Bendix unit). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

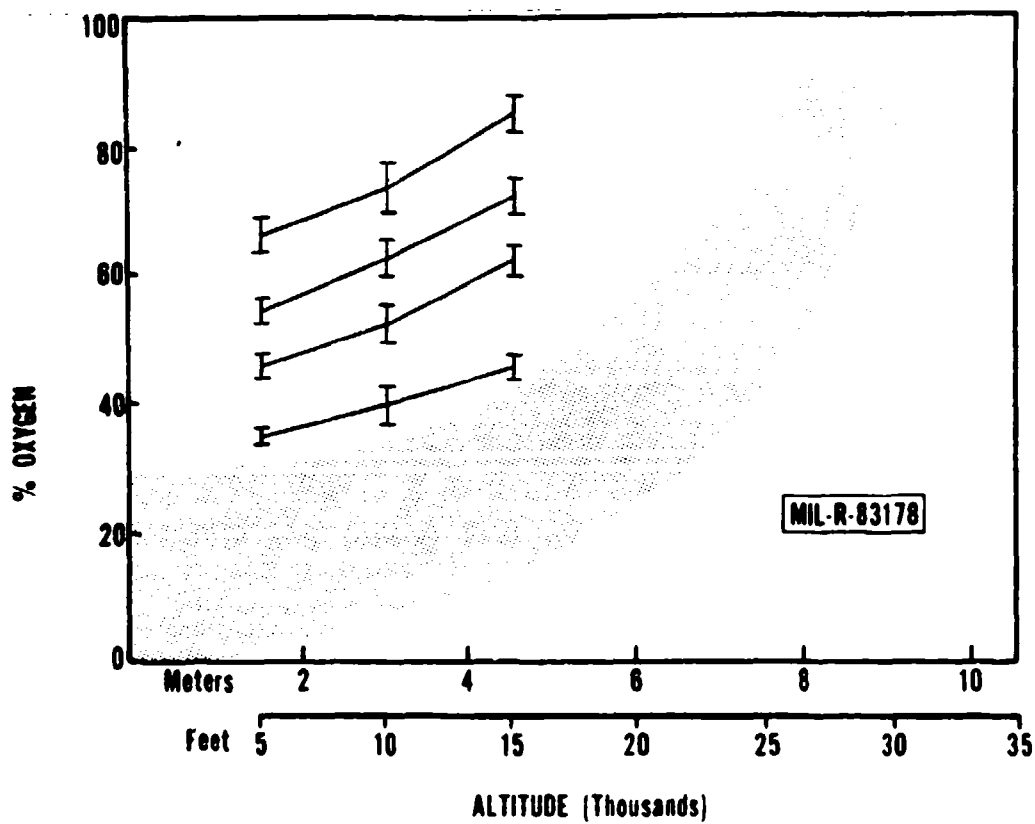


FIGURE 11. Oxygen concentration vs. altitude in JUH-1H (Garrett unit). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

TABLE 1

OXYGEN CONCENTRATION AND SYSTEM CONDITION UNDER STATIC FLOW (BENDIX/JU-21G)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O <sub>2</sub> Conc $\bar{X}$	(%) S <sub>x</sub>
1524 (Min)*	15	41.0	20.1	34.2	30.4	69.3	8.8
	25	41.6	20.6	33.8	30.3	60.8	5.8
	35	41.3	21.9	34.0	30.0	49.7	4.4
	70	42.7	21.6	34.0	28.2	38.3	1.5
1524 (Max)*	15	47.0	23.1	55.2	34.9	67.9	5.2
	25	47.9	23.1	55.2	35.0	63.5	2.9
	35	48.5	23.4	55.0	34.8	54.7	2.4
	70	50.2	23.9	54.2	33.6	40.9	1.7
3048 (Min)	15	47.3	26.1	32.0	28.9	83.6	2.9
	25	46.6	26.5	32.5	28.7	76.5	3.6
	35	45.8	26.6	31.7	28.6	60.3	1.5
	70	45.1	27.1	32.5	27.6	44.6	2.0
3048 (Max)	15	49.4	27.3	49.5	33.8	82.0	7.2
	25	50.4	27.6	49.7	33.6	79.0	3.5
	35	51.2	27.9	50.0	33.4	66.1	2.3
	70	51.7	28.1	49.3	32.5	47.8	1.9
4572 (min)	15	46.7	27.1	30.3	27.8	88.2	6.0
	25	45.3	27.1	30.2	27.5	89.1	5.1
	35	44.4	27.2	30.7	27.6	71.1	4.6
	70	43.9	27.6	30.8	27.5	50.9	3.4
4572 (Max)	15	45.8	27.7	41.5	31.1	86.7	5.4
	25	47.1	27.7	41.8	30.9	85.7	5.5
	35	47.8	27.9	41.8	31.0	75.7	3.9
	70	48.4	28.4	42.0	30.0	53.5	2.7

TABLE 1 (Cont.)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O <sub>2</sub> Conc $\bar{x}$	(%) S <sub>x</sub>
6096 (Min)	15	45.4	25.4	29.4	28.8	88.2	5.1
	25	43.8	25.9	28.8	27.7	88.5	4.9
	35	42.9	26.5	30.2	27.6	83.5	4.4
	70	42.1	26.9	30.1	27.7	58.7	2.5
6096 (Max)	15	43.2	25.9	35.0	30.5	86.8	6.1
	25	43.5	26.0	34.8	30.1	90.1	3.6
	35	43.5	26.2	34.8	29.9	85.6	1.9
	70	43.7	26.4	35.0	29.5	61.9	1.7
7620 (Min/Max)**	15	42.3	27.2	29.4	27.8	89.7	5.5
	25	41.9	26.9	29.8	27.5	89.8	5.8
	35	41.6	26.8	29.6	27.4	88.8	5.8
	70	41.5	26.8	29.2	27.2	69.2	2.8

\*Minimum power defined as 130 knots IAS. Maximum power defined as 208 knots IAS with ITT not to exceed 705°C.

\*\*At 7620 meters, minimum and maximum power setting is the same.

TABLE 2

OXYGEN CONCENTRATION AND SYSTEM CONDITION UNDER STATIC FLOW (GARRETT/JU-21G)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O <sub>2</sub> Conc $\bar{x}$	S <sub>x</sub>
1524 (Min)*	15	35.9	20.8	34.2	27.6	64.5	6.0
	25	38.0	20.5	34.8	27.1	57.7	1.9
	35	39.0	20.5	35.0	26.7	46.3	2.3
	70	40.1	20.5	35.6	26.7	33.7	1.9
1524 (Max)*	15	43.6	21.4	54.2	33.9	64.7	2.0
	25	44.6	21.0	54.5	33.9	55.7	5.9
	35	45.4	21.1	54.5	33.7	46.0	4.1
	70	46.1	21.5	54.2	33.0	34.0	2.7
3048 (Min)	15	43.7	22.1	34.0	27.2	78.1	8.4
	25	43.0	22.3	33.4	27.2	72.6	7.9
	35	42.5	22.5	32.6	26.3	55.9	5.9
	70	42.1	22.6	32.2	25.5	40.3	3.2
3048 (Max)	15	45.9	23.3	53.0	27.4	73.5	4.2
	25	47.0	23.4	52.6	26.8	67.4	6.6
	35	47.8	23.3	53.2	26.0	55.7	4.9
	70	48.3	23.5	50.2	26.0	38.6	4.1
4572 (Min)	15	41.5	25.0	30.0	25.5	84.6	2.2
	25	40.4	24.8	30.8	25.2	80.9	4.7
	35	39.5	24.5	31.2	25.1	67.5	3.6
	70	38.8	26.0	30.8	24.8	47.2	3.9
4572 (Max)	15	38.7	23.6	45.4	24.3	75.7	3.8
	25	40.1	23.1	44.8	24.2	75.1	4.0
	35	41.4	22.8	44.6	24.2	60.0	4.0
	70	42.4	22.9	44.0	23.5	46.0	2.2

TABLE 2 (Cont.)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O <sub>2</sub> Conc $\bar{X}$	(%) $S_x$
6096 (Min)	15	41.3	23.8	29.2	26.8	86.0	5.8
	25	40.3	24.2	29.2	24.7	84.4	5.4
	35	39.5	24.7	28.8	24.4	78.7	5.2
	70	38.9	24.9	28.8	25.0	57.2	9.4
6096 (Max)	15	39.2	25.8	41.0	25.5	81.2	3.7
	25	40.0	26.0	40.0	24.7	81.8	3.7
	35	40.6	26.2	40.0	24.1	73.5	4.2
	70	41.2	26.3	39.0	23.8	52.7	3.4
7620 (Min/Max)**	15	40.0	25.6	31.2	24.5	82.1	9.5
	25	39.5	25.3	31.6	24.4	88.7	4.6
	35	39.1	25.1	30.8	24.1	83.4	3.4
	70	38.9	24.7	31.4	24.6	63.8	3.3

\*Minimum power defined as 130 knots IAS. Maximum power defined as 208 knots IAS with ITT not to exceed 705°C.

\*\*At 7620 meters, minimum and maximum power setting is the same.

TABLE 3

OXYGEN CONCENTRATION AND SYSTEM CONDITION UNDER STATIC FLOW (BENDIX/JUH-1H)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O <sub>2</sub> Conc X	(%) S <sub>x</sub>
1524	15	42.7	23.3	53.0	26.8	58.7	4.0
	25	41.9	23.3	53.0	26.5	50.0	2.1
	35	42.1	23.6	52.8	26.3	44.4	2.1
	70	43.2	25.2	52.8	25.1	35.9	1.6
3048	15	42.5	24.1	47.0	25.7	65.3	2.7
	25	42.5	24.1	46.6	25.4	56.6	2.0
	35	42.6	24.2	46.8	25.2	51.3	1.5
	70	43.6	25.6	46.6	24.4	40.8	1.2
4572	15	44.5	21.6	43.1	26.3	89.1	2.8
	25	44.1	19.3	42.9	25.9	79.0	0.6
	35	43.2	17.5	42.7	25.8	71.3	2.7
	70	43.2	16.8	42.4	25.3	50.6	1.8

TABLE 4

## OXYGEN CONCENTRATION AND SYSTEM CONDITION UNDER STATIC FLOW (GARRETT/JUH-1H)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O <sub>2</sub> Conc $\bar{x}$	S <sub>x</sub> (%)
1524	15	44.4	24.1	52.8	22.2	66.2	2.6
	25	45.1	23.8	52.2	22.1	54.3	2.0
	35	45.6	23.8	52.6	22.0	45.3	1.7
	70	46.7	24.6	52.6	21.3	34.8	1.8
3048	15	46.3	24.1	47.4	22.0	74.0	4.3
	25	46.4	23.7	47.6	22.1	62.4	2.4
	35	46.4	23.3	47.6	22.2	53.2	2.7
	70	47.0	23.7	47.2	21.5	39.7	2.2
4572	15	47.8	19.9	43.7	21.8	85.5	3.1
	25	46.6	18.7	43.1	21.7	72.9	3.0
	35	46.0	17.9	43.0	21.4	62.1	2.3
	70	46.0	17.7	42.7	20.9	45.7	2.0

TABLE 5

## OXYGEN CONCENTRATION AND SYSTEM CONDITION UNDER STATIC FLOW (GARRETT/JU-21G)

## SUPPLEMENTAL DATA

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O <sub>2</sub> Conc $\bar{x}$	S <sub>x</sub>
1524 (Min)	15	46.9	26.8	36.1	22.3	77.6	1.4
	25	45.9	26.0	37.0	22.1	59.4	2.9
	35	48.6	25.5	36.8	22.2	49.6	1.0
	70	49.0	25.9	36.4	21.3	36.6	0.3
1524 (Max)	15	50.4	25.2	61.4	23.1	72.8	2.0
	25	52.7	24.9	61.1	23.0	54.4	1.3
	35	53.3	24.7	61.0	22.7	46.0	0.4
	70	57.1	25.5	60.3	21.8	35.2	0.6
3048 (Min)	15	50.5	24.5	34.8	23.1	85.8	4.9
	25	48.3	24.1	34.7	23.0	70.2	6.9
	35	47.8	24.4	34.6	23.1	56.2	1.6
	70	48.2	25.1	30.6	22.5	40.6	1.8
3048 (Max)	15	49.6	25.1	53.6	22.7	75.3	0.8
	25	50.8	25.2	53.6	22.5	60.4	1.4
	35	51.6	25.8	53.2	22.3	51.0	1.2
	70	52.3	26.9	53.0	21.5	37.6	0.4
4572 (Min)	15	49.4	26.1	30.4	22.5	84.4	2.4
	25	48.5	26.1	30.8	22.7	71.4	1.3
	35	48.1	26.1	30.8	22.7	59.1	1.4
	70	48.1	26.8	30.1	21.9	41.4	0.4

TABLE 5 (Cont.)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O <sub>2</sub> Conc $\bar{x}$	(%) $S_x$
4572 (Max)	15	50.8	26.3	46.3	22.4	76.0	4.5
	25	51.2	26.2	46.4	22.8	64.2	2.7
	35	51.4	26.2	46.4	22.4	55.9	1.1
	70	51.6	27.0	46.2	22.0	39.7	0.7
6096 (Min)	15	51.2	24.9	33.7	23.1	92.1	3.0
	25	47.5	24.0	35.3	22.9	83.2	3.1
	35	47.6	23.5	35.0	22.7	72.3	3.7
	70	48.5	23.5	34.5	22.7	50.4	1.9
6096 (Max)	15	52.5	23.6	40.3	22.7	88.7	4.0
	25	53.3	22.8	40.4	22.6	78.0	3.1
	35	54.1	22.8	40.1	22.4	67.8	2.7
	70	54.7	23.1	40.1	21.9	50.1	2.6
7620 (Min/Max)	15	46.6	21.5	34.0	23.2	90.5	3.7
	25	44.8	20.7	33.9	23.0	88.7	1.7
	35	44.3	20.2	33.9	23.0	78.7	2.8
	70	44.1	20.1	31.9	22.9	56.0	1.3

suffered a lightning strike. The aircraft main electrical inverters malfunctioned and the motor in the Bendix On-Board Oxygen Generating System (OBOGS) unit would not operate in the laboratory after the flight. The unit is being repaired. No additional data for the Bendix unit is reported.

Other aircraft flight parameters which were recorded, but not included in this report were engine torque and ITT or exhaust gas temperature. There was no noticeable difference in the instrumentation readings nor could the pilots "feel" when the concentrators were being driven by bleed air.

## DISCUSSION

Static testing of the molecular sieve concept of onboard oxygen concentration systems for the Army aircraft is a necessary first step to insure their physiological adequacy. Although each unit met or exceeded the requirements of MIL-R-83178, the results obtained in the JUH-1H helicopter differed from those obtained in the JU-21G fixed-wing aircraft. A comparison of these results shows that the Garrett unit performed similarly in both aircraft when the JU-21G was at maximum power. The Bendix unit, however, in some instances, produced a lower oxygen concentration in the JUH-1H than in the JU-21G. A comparison of these data with the data in Table 1 of Ernsting et al. (1980) reveals that operation of these units in flight produces oxygen concentrations slightly higher with the Garrett unit and slightly lower with the Bendix unit than the respective values obtained during tests in the hypobaric chamber.

The oxygen concentration process of the molecular sieve depends on many factors including flow, inlet temperature, inlet pressure, and the pressure differential across the molecular sieve bed. Additionally, although the cause has not been definitely determined, the resistance of the nitrogen exhaust purge hose seems to be a factor and attention should be directed to the design of an exhaust port to maximize oxygen concentration. The differences in oxygen concentration reported here and those reported by Ernsting are probably a result of differences in all of these factors. One notable difference in test procedures was our use of heated engine bleed air instead of unheated laboratory instrument air as used in Ernsting's hypobaric chamber tests. Both units have internal pressure regulators which limit the inlet pressure to between 25 and 28 psig. This effectively eliminates the effect of bleed air pressure changes that might result from differing engine power settings since even minimum engine power settings produce bleed air pressure in excess of 25 psig.

The use of engine bleed air to drive the oxygen concentrators produced no noticeable effect on aircraft performance.

During the upcoming toxicology phase of this project, in which tests will be conducted to determine whether or not any harmful substances from

bleed air exhaust are passed through the molecular sieve, the noted variables will be studied more closely and an attempt will be made to optimize them for maximum oxygen production.

The results in Table 5 and Figures 12 and 13 confirm the hypothesis that some early readings were taken prior to system equilibrium. This means that the first set of data is slightly more conservative in stating oxygen output at low flows and at the lower altitudes.

The primary objective of the study was to assess the physiological adequacy of these molecular sieve oxygen concentration units in order to qualify them for human use so that dynamic-human interface can be studied in flight. The results obtained indicate that both units generate enough oxygen to support two human subjects in a dynamic breathing study. There is a possibility that two aviators under high workload conditions (e.g. Night NOE with NVG) would require minute volumes greater than these systems can produce.

### CONCLUSIONS

Oxygen production by each of the molecular sieve oxygen concentrators studied met or exceeded the requirements of MIL-R-83178 at all flows and altitudes. Both units have shown themselves capable of producing the oxygen required at normal minute volumes for a one- or two-man crew on the JUH-1H and JU-21G aircraft. However, in cases where no air mix is allowed and the aviators are under high stress, it would be possible for two aviators to attempt to over breathe the system. Prior to initial human interface studies, however, it will be necessary to complete product gas toxicology tests to insure that contaminants from aircraft engine bleed air are not passed through the concentrators in harmful amounts.

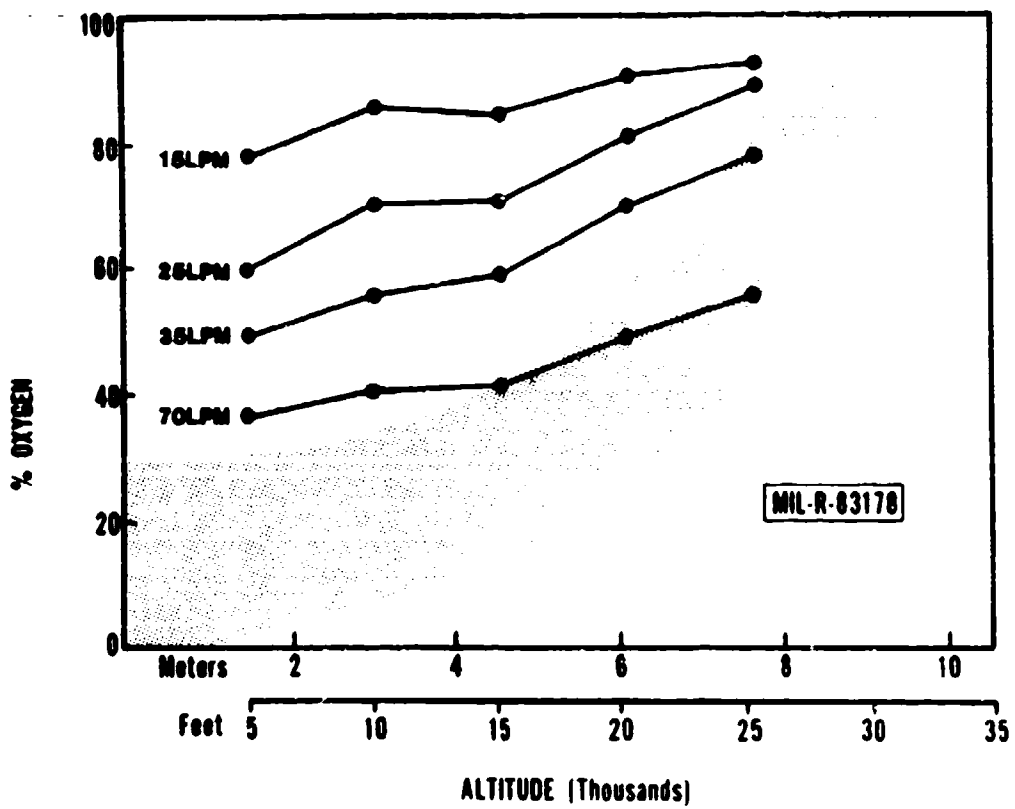


FIGURE 12. Garrett Minimum Power - JU-21G. (Supplemental Data)

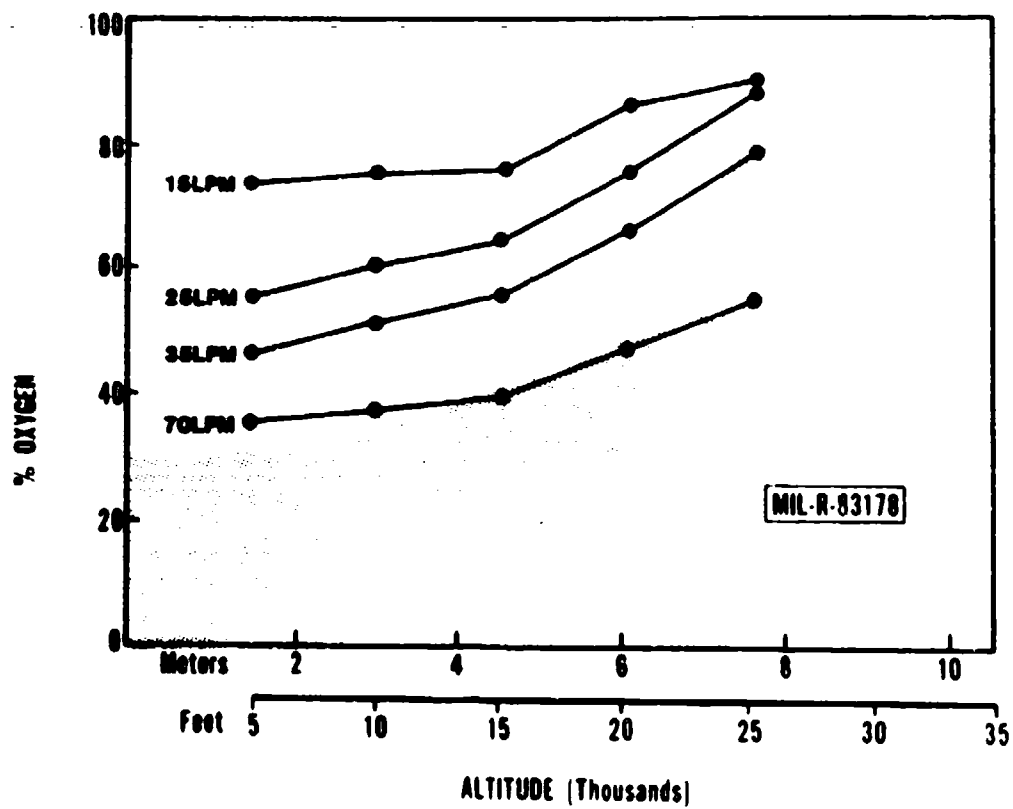


FIGURE 13. Garrett Maximum Power - JU-21G. (Supplemental Data)

## REFERENCES CITED

- Ernsting, J., Armstrong, R. N., Hiott, B. F., and Holden, R. D. 1980. *A physiological evaluation of two types of molecular sieve generation systems*. Preprints of the scientific program, Aerospace Medical Association, 1980 Annual Scientific Meeting; Anaheim, CA. pp. 131-132.
- Knox, F. S., Hiott, B. F., Alexander, J., Jr., and Biggs, F. 1981. *Evaluation of onboard oxygen systems for U.S. Army aircraft*. Preprints of the Scientific Program, Aerospace Medical Association, 1981 Annual Scientific Meeting; San Antonio, TX. pp. 195-196.
- Miller, R. L., Ikels, K. G., Lamb, M. J., Brooks, E. J., and Ferguson, R. H. 1980. *Molecular sieve generation of aviator's oxygen: Performance of a prototype under simulated flight conditions*. Aviation, Space and Environmental Medicine 51(7):665-673
- Pettyjohn, F. S., McNeil, R. J., Akers, L. A., Rice, G. P., and Piper, C. F. 1977. *Aeromedical evaluation of the Army molecular sieve oxygen generation (AMSOG) systems*. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report 77-10.
- Department of Defense. 1974. *General Specifications for Regulator, Oxygen, Diluter Demand, and Automatic Pressure Breathing*. Washington, DC: Dept. of Defense. MIL-R-83178.

APPENDIX A

EQUIPMENT AND MANUFACTURER LIST

## EQUIPMENT AND MANUFACTURER LIST

Molecular Sieve Oxygen Generator  
Model 2202490-1-1  
Serial #49-R1  
AirResearch Mfg Co. of California  
Garrett Corporation

Validyne Differential Pressure  
Transducer  
1914 Londelius Street  
Northridge, California 91324

Technology Incorporated, Mass  
Flow Meter  
Dayton, Ohio 45431

Harris Pressure Gauge  
Melbourne, Florida 32901

Wallace and Tiernan Barometer  
Belleville, New Jersey 07109

Molecular Sieve Oxygen Concentrator  
Model 99251-3261009-0105  
Serial #90801 5E  
\*Bendix Instruments and Life Support  
Division  
Davenport, Iowa 52802

Beckman OM-14 Oxygen Analyzer  
2500 Harbor Boulevard  
Fullerton, California 92634

Cole-Palmer Digital Thermometer  
Chicago, Illinois 60648

Fischer-Porter Rotameter  
Warminster, Pennsylvania 18974

\*Now known as Clifton Precision

## INITIAL DISTRIBUTION

Commander  
US Army Natick R & D Laboratories  
ATTN: Tech Librarian  
Natick, MA 01760

Commander  
US Army Research Institute of  
Environmental Medicine  
Natick, MA 01760

US Navy  
Naval Sub Med Rsch Lab  
Med Library, Naval Submarine Base  
Box 900  
Groton, CT 06340

US Army Avionics R & D Activity  
ATTN: DAVAA-O  
Fort Monmouth, NJ 07703

Cdr/Dir  
US Army Combat Surveillance &  
Target Acquisition Lab  
ATTN: DELCS-D  
Fort Monmouth, NJ 07703

US Army R & D Technical  
Support Activity  
Fort Monmouth, NJ 07703

Commander  
10th Medical Laboratory  
ATTN: DEHE (Audiologist)  
APO New York 09180

Chief  
Benet Weapons Laboratory  
LCWSL, USA ARRADCOM  
ATTN: DRDAR-LCB-TL  
Watervliet Arsenal  
Watervliet, NY 12189

Commander  
Naval Air Development Center  
Biophysics Lab (ATTN: George Kydd)  
Code 60B1  
Warminster, PA 18974

Human Factors Engr Div  
Acft & Crew Systems Tech Dir  
Naval Air Development Center  
Warminster, PA 18974

Naval Air Development Center  
Tech Info Div  
Technical Support Department  
Warminster, PA 18974

Commander  
Naval Air Development Center  
ATTN: Code 6022 (Mr. Brindle)  
Warminster, PA 18974

Dr. E. Hendler  
Code 6003  
Naval Air Development Center  
Warminster, PA 18974

Director  
Army Audiology & Speech Center  
Walter Reed Army Medical Center  
Forest Glen Section, Bldg 156  
Washington, DC 20012

Director  
Walter Reed Army Institute  
of Research  
Washington, DC 20012

Commander  
US Army Institute of  
Dental Research  
Walter Reed Army Medical Center  
Washington, DA 20012

Uniformed Services University  
of the Health Sciences  
4301 Jones Bridge Road  
Bethesda, MD 20014

Commanding Officer  
Naval Medical R & D Command  
National Naval Medical Center  
Bethesda, MD 20014

Under Secretary of Defense for  
Research and Engineering  
ATTN: Mil Asst for Medical  
and Life Sciences  
Washington, DC 20301

Director of Professional Services  
Office of The Surgeon General  
Department of the Air Force  
Washington, DC 20314

Naval Air Systems Command  
Tech Library Air 950D  
Rm 278, Jefferson Plaza II  
Department of the Navy  
Washington, DC 20361

US Navy  
Naval Research Lab Library  
Code 1433  
Washington, DC 20375

US Navy  
Naval Research Lab Library  
Shock & Vibration Info Ctr  
Code 8404  
Washington, DC 20375

Harry Diamond Laboratories  
Scientific & Technical  
Information Offices  
2800 Powder Mill Road  
Adelphi, MD 20783

Director  
US Army Human Engineering  
Laboratory  
ATTN: Tech Library  
Aberdeen Proving Ground, MD  
21005

US Army Material Systems  
Analysis Agency  
ATTN: Reports Dist  
Aberdeen Proving Ground, MD  
21005

US Army Ordnance Center  
and School  
Library, Bldg 3071  
ATTN: ATSL-DOSL  
Aberdeen Proving Ground, MD  
21005

Director  
Ballistics Research Lab  
ATTN: DRDAR-TSB-C (STINFO)  
Aberdeen Proving Ground, MD  
21005

US Army Environmental Hygiene  
Agency Library, Bldg E2100  
Aberdeen Proving Ground, MD  
21010

Commander  
US Army Med Rsch Institute  
of Chemical Defense  
Aberdeen Proving Ground, MD  
21010

Technical Library  
Chemical Systems Laboratory  
Aberdeen Proving Ground, MD 21010

Commander  
US Army Medical R & D Command  
ATTN: SGRD-RMS (Mrs. Madigan)  
Fort Detrick  
Frederick, MD 21701

Commander  
US Army Med Rsch Institute  
of Infectious Diseases  
Fort Detrick  
Frederick, MD 21701

Commander  
US Army Med Bioengineering  
R & D Laboratory  
Fort Detrick  
Frederick, MD 21701

Dir of Biol & Med Sciences Div  
Office of Naval Research  
800 N. Quincy Street  
Arlington, VA 22217

Defense Technical  
Information Center  
Cameron Station, VA 22314

US Army Materiel Development &  
Readiness Command  
ATTN: DRCSG  
5001 Eisenhower Avenue  
Alexandria, VA 22333

US Army Foreign Science &  
Technology Center  
ATTN: DRXST-IS1  
220 7th Street, NE  
Charlottesville, VA 22901

Commander  
US Army Transportation School  
ATTN: ATSP-TD-ST  
Fort Eustis, VA 23604

Commander  
US Army Airmobility Laboratory  
ATTN: Library  
Fort Eustis, VA 23604

US Army Training and  
Doctrine Command  
ATTN: ATCD  
Fort Monroe, VA 23651

Commander  
US Army Training and  
Doctrine Command  
ATTN: Surgeon  
Fort Monroe, VA 23651

US Army Research and  
Technology Laboratory  
Structures Laboratory Library  
NASA Langley Research Center  
Mail Stop 266  
Hampton, VA 23665

US Navy  
Naval Aerospace Medical  
Institute Library  
Bldg 1953, Code 102  
Pensacola, FL 32508

US Air Force  
Armament Development and  
Test Center  
Eglin Air Force Base, FL 32542

Colonel Stanley C. Knapp  
US Central Command  
CCSG MacDill AFB, FL 33608

Redstone Scientific Information  
Center  
DRDMI-TBD  
US Army Missile R & D Command  
Redstone Arsenal, AL 35809

Air University Library  
(AUL/LSE)  
Maxwell AFB, AL 36112

Commander  
US Army Aeromedical Center  
Ft Rucker, AL 36362

Commander  
US Army Avn Center &  
Fort Rucker  
ATTN: ATZQ-CDR  
Ft Rucker, AL 36362

Director  
Directorate of Combat  
Developments  
Bldg 507  
Ft Rucker, AL 36362

Director  
Directorate of Training  
Development  
Bldg 502  
Ft Rucker, AL 36362

Chief  
Army Research Institute  
Field Unit  
Ft Rucker, AL 36362

Commander  
US Army Safety Center  
Ft Rucker, AL 36362

Commander  
US Army Aviation Center  
& Fort Rucker  
ATTN: ATZQ-T-ATL  
Ft Rucker, AL 36362

Commander  
US Army Aircraft  
Development Test Activity  
ATTN: STEBG-MP-QA  
Cairns AAF  
Ft Rucker, AL 36362

President  
US Army Aviation Board  
Cairns AAF  
Ft Rucker, AL 36362

Canadian Army Liaison Officer  
Bldg 602  
Ft Rucker, AL 36362

Netherlands Army Liaison Office  
Bldg 602  
Ft Rucker, AL 36362

German Army Liaison Office  
Bldg 602  
Ft Rucker, AL 36362

British Army Liaison Office  
Bldg 602  
Ft Rucker, AL 36362

French Army Liaison Office  
Bldg 602  
Ft Rucker, AL 36362

US Army Research and  
Technology Labs  
Propulsion Laboratory MS 77-5  
NASA Lewis Research Center  
Cleveland, OH 44135

Human Engineering Division  
Air Force Aerospace Medical  
Research Laboratory  
ATTN: Technical Librarian  
Wright Patterson AFB, OH  
45433

US Air Force Institute of  
Technology (AFIT/LDE)  
Bldg 640, Area B  
Wright-Patterson AFB, OH 45433

John A. Dellinger, MS, ATP  
Univ of Ill - Willard Airport  
Savoy, IL 61874

Henry L. Taylor  
Director  
Institute of Aviation  
Univ of Ill - Willard Airport  
Savoy, IL 61874

Commander  
US Army Troop Support and  
Aviation Material Readiness Cmd  
ATTN: DRSTS-W  
St Louis, MO 63102

Commander  
US Army Aviation Systems Command (Prov)  
ATTN: SGRD-UAX-AL (Maj Lacy)  
Bldg 105  
4300 Goodfellow Boulevard  
St Louis, MO 63166

Commander  
US Army Aviation Systems Command (Prov)  
ATTN: DRDAV-E  
4300 Goodfellow Blvd  
St Louis, MO 63166

Commander  
US Army Aviation Systems Command (Prov)  
ATTN: Library  
4300 Goodfellow Blvd  
St Louis, MO 63166

Commanding Officer  
Naval Biodynamics Laboratory  
PO Box 24907  
Michoud Station  
New Orleans, LA 70129

Federal Aviation Administration  
Civil Aeromedical Institute  
ATTN: Library  
Box 25082  
Oklahoma City, OK 73125

US Army Field Artillery School  
ATTN: Library  
Snow Hall, Room 14  
Fort Sill, OK 73503

Commander  
US Army Academy of Health Sciences  
ATTN: Library  
Ft Sam Houston, TX 78234

Commander  
US Army Health Services Command  
ATTN: Library  
Ft Sam Houston, TX 78234

Commander  
US Army Institute of  
Surgical Research  
Ft Sam Houston, TX 78234

US Air Force  
Aerospace Medical Division  
School of Aerospace Medicine  
Aeromedical Library/TSK-4  
Brooks AFB, TX 78235

US Army  
Dugway Proving Ground  
Technical Library  
Bldg 5330  
Dugway, UT 84022

Dr. Diane Damos  
Psychology Department  
Arizona State University  
Tempe, AZ 85287

US Army Yuma Proving Ground  
Technical Library  
Yuma, AZ 85364

US Army White Sands Missile Range  
Technical Library Division  
White Sands Missile Range  
New Mexico, 88002

US Air Force  
Flight Test Center  
Technical Library, Stop 238  
Edwards AFB, CA 93523

US Army Aviation Engineering  
Flight Activity  
ATTN: DAVTE-M (Tech Lib)  
Edwards AFB, CA 93523

US Navy  
Naval Weapons Center  
Tech Library Division  
Code 2333  
China Lake, CA 93555

US Army Combat Developments  
Experimental Command  
Technical Library  
Hq, USACDEC  
Box 22  
Ft Ord, CA 93941

Aeromechanics Laboratory  
US Army Rsch & Tech Labs  
Ames Research Center, M/S 215-1  
Moffett Field, CA 94035

Commander  
Letterman Army Institute of Rsch  
ATTN: Med Rsch Library  
Presidio of San Francisco  
CA 94129

Sixth US Army  
ATTN: SMA  
Presidio of San Francisco  
CA 94129

Director  
Naval Biosciences Laboratory  
Naval Supply Center, Bldg 844  
Oakland, CA 94625

Col G. Stebbing  
DAO-AMLOUS B  
Box 36, US Embassy  
FPO New York 09510

Staff Officer, Aerospace Medicine  
RAF Staff  
British Embassy  
3100 Massachusetts Ave, NW  
Washington, DA 20008

Department of Defence  
R.A.N. Resch Laboratory  
P.O. Box 706  
Darlinghurst, N.S.W. 2010  
Australia

Canadian Society of Avn Med  
c/o Acad of Med, Toronto  
ATTN: Ms Carmen King  
288 Bloor Street West  
Toronto, Ontario  
M5S 1V8

Canadian Air Line Pilot's Assn  
MAJ J. Soutendam (Ret)  
1300 Steeles Ave East  
Brampton, Ontario, Canada  
L6T 1A2

Canadian Forces Med Ln Off  
Canadian Defence Ln Staff  
2450 Massachusetts Ave, NW  
Washington, DC 20008

Commanding Officer  
404 Maritime Training Squadron  
Canadian Forces Base Greenwood  
Greenwood, N.S. BOP 1N0 Canada  
ATTN: Aeromed Tng Unit

Officer Commanding  
School of Operational and  
Aerospace Medicine  
DCIEM  
PO Box 2000  
1133 Sheppard Avenue West  
Downsview, Ontario, Canada  
M3M 3B9

National Defence Headquarters  
101 Colonel By Drive  
Ottawa, Ontario Canada  
K1A 0K2  
ATTN: DPM